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A Study on mechanical and tribological properties of MMCs fabricated using different fly ashes with eutectic Al–Si alloy

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ABSTRACT

In recent years, aluminium matrix composites reinforced with ceramic particulates have been pivot of attraction for researchers due to their inherent good mechanical properties and low cost. In this investigation, composites have been produced with two different varieties of fly ash which are being used as reinforcement material on eutectic Al–Si alloy as the matrix. The prime objective of this study is to determine which composition of fly ash proves better enhancement for the composite being formed, basing upon some prime mechanical parameters such as tensile strength, hardness and wear resistance. Stir casting route has been adopted to disperse fly ash in the Al–Si alloy matrix. These composites along with the base alloys were subjected to wear test by using DUCOM wear and friction monitor, tensile test using tensometer & hardness through Brinell hardness test. The test results indicated that all the above properties got enhanced in the composites as compared to the base alloy, but the properties of composites prepared using fly ash of variety 1 indicated more enhancements as compared to that of composite formed using fly ash of variety 2.

Keywords: metal matrix composites, fly ash, mechanical properties, wear, hardness, tensile strength.

1. INTRODUCTION

Fibers or particles embedded in matrix of another material are the best example of modern-day composite materials, which are mostly structural. In matrix-based structural composites, the matrix serves two prime purposes viz., binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force & hence reinforcing materials generally withstand maximum load and serve the desirable properties. Metal–matrix composites are materials in which tailored properties are achieved by systematic combinations of various constituents [1]. Metal matrix composites, at present are generating a wide interest in the field of research. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites.

2. EUTECTIC AL–SI ALLOY (LM6)

Eutectic Al–Si alloy (LM6) is one of the commonly used alloys in the non-heat treated condition for automotive engines because of its good mechanical properties, high strength-to-weight ratio, wear resistance and low coefficient of expansion. Apart from stress relieving and improvement in ductility, heat treatment does not significantly change the properties of such alloys [2].

3. REINFORCING AGENT FLY ASH

In this experiment, fly ash-an industrial waste is used as reinforcement material. Fly ash is a byproduct of coal combustion collected from electrostatic precipitators and bottom ash at the bottom of furnaces. It is a fine-grained, powder material that is carried off in flue gas and usually collected by means of electrostatic precipitators, bag housings, or mechanical collection devices such as cyclones. Fly ash obtained from electrostatic precipitators varies in size from 5μm to 75 μm [3].

4. EXPERIMENTAL PROCEDURE

Chemical composition of matrix & reinforcements used:

Eutectic Al-Si alloy LM6 containing 12.2491% Si was used as the matrix. The composition of the alloy is as shown below in table-1.

Table-1

Co	Si	Fe	Cu	Mn	Ti	Zn
0.0174	12.2491	0.4353	0.0800	0.1601	0.0672	0.0944
Pb	**Sn**	**Cr**	**Ca**	**V**	**Al**	**Ni**
0.0525	0.0632	0.0199	0.0082	0.0146	86.7654	0.0264

Chemical composition of fly ash variety-1 and variety-2 are as shown in table-2 and 3 respectively.

Table-2

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	C	K_2O
(Wt. %)	68.41	20.73	4.97	0.62	0.46	5.60	0.97

Table-3

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
(Wt. %)	63.34	24.60	4.97	1.23	0.56	0.11	0.64

(Figure 1)

Fabrication of composites

At the beginning of the process the LM6 ingots were placed in a crucible and subjected to a pre-melting heat treatment process for 2 hours at 450°C using an electrically heated furnace. This

process was implemented in order to have better distribution of SiC particles in the molten metal [4] .There after the heat treated LM6 material was proceeded for melting operation in the melting furnace as shown in (figure 1) in side which, the material was melted at 670ºC.

During the melting interval, the fly ash was also subjected to a heat treatment process for 2 hours at 650ºC with the help of electrical melting furnace. Now, the heated fly ash were added into the molten LM6 present inside the melting furnace and was manually stirred for 2-3 minutes and then subjected to auto stirring with the help of a motor driven stirrer setup attached with the furnace at a constant speed of 455RPM for 15 minutes. Degassing of molten metal was carried out by passing dry Argon gas in the molten metal throughout the fabrication process. The metal pouring mould was subjected to a heating process till it achieved a temperature of 650ºC with the constant supply of LPG along with air as shown in figure 3.3. The molten metal was poured into the mould at 500-600ºC temperature. The castings so produced, were taken out of the die, cooled then cut & machined to get standard test specimens for determining hardness, ultimate tensile strength and wear as per the dimensional requirement of the samples. Same process was used to fabricate both:

1.LM6/15wt % fly ash A particle (240 mesh) Composite-1.

2.LM6/15 wt % fly ash B particle (240 mesh) Composite-2.

But the weight calculations after the completion of casting showed that Composite-1 so formed has accepted 13wt% of fly ash A out of 15% whereas Composite-2 accepted 11wt% of fly ash B. The reasons behind these phenomenons are well explained in the results and discussion section.

Hardness

Brinnel hardness test was conducted on the specimens using a standard Brinnel hardness tester (Figure 2). A load of 250 kg was applied on the specimen for 30 seconds using a 5mm ball indenter and the indentation diameter was measured using a micrometer microscope. Four of such indentations were made on each of the specimens and the corresponding BHN was found out by taking the average of the four. The Brinnel hardness number (BHN) was computed using the formula:

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

where P is the load applied, D the diameter of the ball indenter and d is the diameter of indentation. Below are the pictures of the Brinnel hardness tester and a specimen under test.

(Figure 2)

Ultimate tensile strength (UTS) and elongation

An electronic tensometer was employed for tensile testing. The tensometer specimens were loaded one after another between two grips that were adjusted manually. A constantly increasing force was applied to the specimen by electronic means. The load and elongation were continuously recorded digitally with the help of computer. The UTS and percentage elongation were calculated. The followings are the pictures of the tensometer (Figure 3) and the specimens before and after the experiment (Figure 4).

(Figure 3)


Tensometer samples before test


Tensometer samples after test

(Figure 4)

Figure 5 Pin on disc arangement

Figure 6 Wear sample after wear test

Wear Test

A dry sliding wear test was conducted in ambient conditions using a pin on disc DUCOM wear testing machine with a data acquisition system. Wear was determined by the weight loss method. The test samples having the dimensions of 8 mm diameter and 40 m length (Figure 6) are slide against the low alloy steel disc (material EN-31-HRS 60 W 61 equal to 4340) of dia 215 mm, and Hardness R_c 62 at a load of 50N for 3000 seconds at a speed of $2ms^{-1}$.

5. RESULTS AND DISCUSSION

The image analysis of the composites proved that the fly ash is uniformly distributed throughout the Al-Si matrix as shown in Figure 7.2 and Figure 7.3.

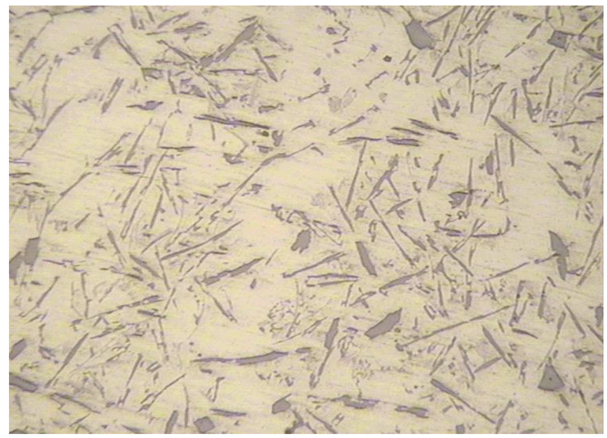


Figure 7.1 Al-Si Matrix

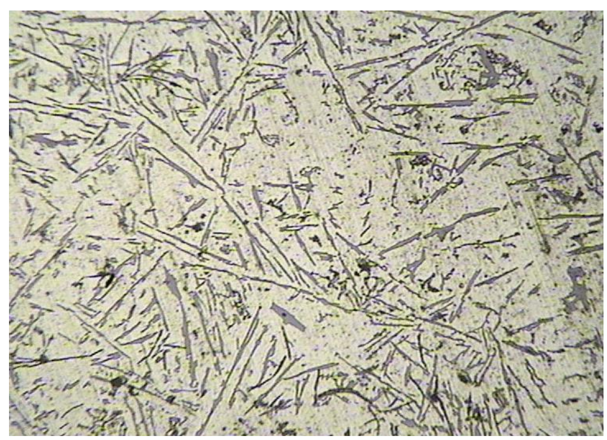


Figure 7.2 Composite-1

The reasons behind acceptance of 13% fly ash A by composite-1 and 11% of fly ash B by composite-2 out of 15% can be derived from the results obtained from SEM analysis of the fly ashes. The SEM micrographs of fly ash A and fly ash B are as shown in Figure 8.1 and Figure 8.2 respectively. From the figure it can be clearly observed that fly ash A has an irregular

particle geometry and hence it can easily manage to well fit into various voids present in the matrix where as fly ash B has a regular particle geometry (almost spherical), so it requires its equivalent voids to be present in the matrix in order to get properly reinforced in to the matrix. The fly ash A also contains a major percentage of Carbon (Table-2), an ingredient which sufficiently enhances wettability of the matrix.

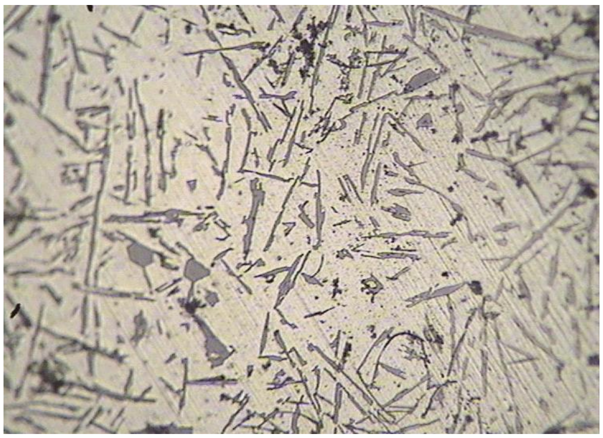


Figure 7.3 Composite-2

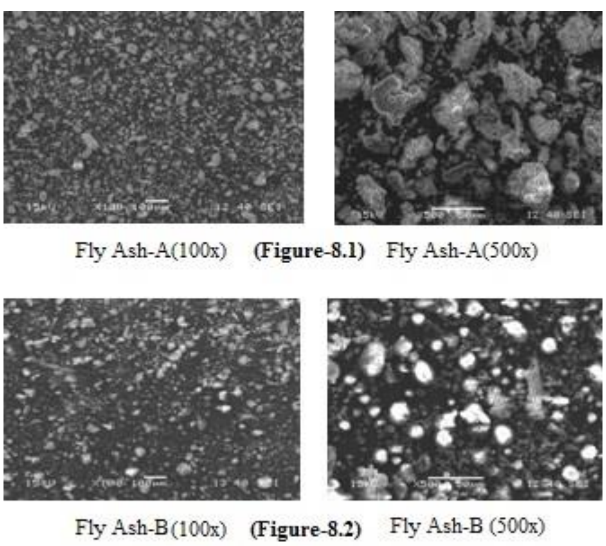
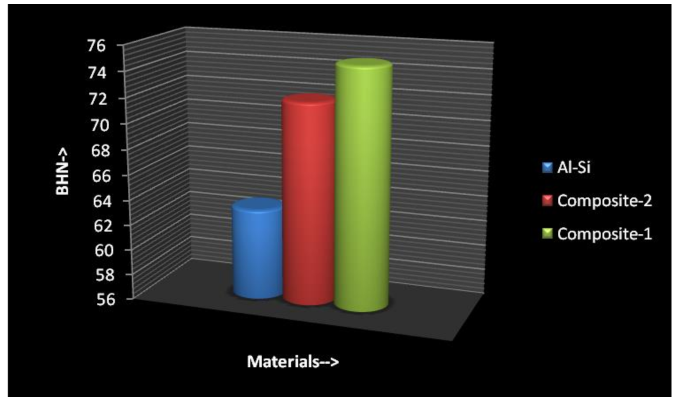


Figure 8 SEM Micrographs

A. Hardness

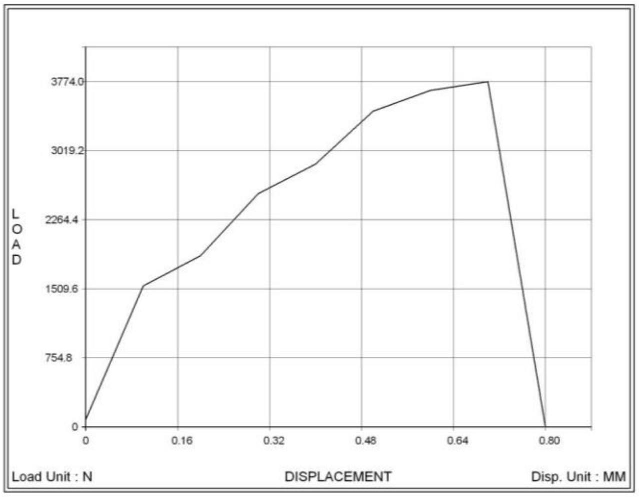
The result shows an increase in hardness with the addition of fly ash, when compared with the unreinforced eutectic Al–Si alloy (63.2 BHN). For instance, hardness was found to be 74.9 BHN for first composite (an increase of 18.5 % over the base alloy) and 71.925 BHN for second composite (an increase of 13.8% over the base alloy). It has been reported that addition of ceramic particles increases the hardness of composites [5]. The increase in hardness is expected because of the presence of ceramic reinforcements which are very hard, and act as barriers to the movement of dislocations within the matrix and exhibit greater resistance to indentation [6]



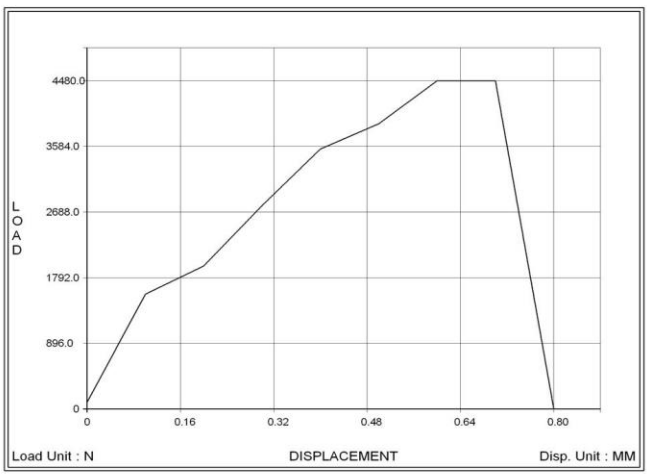
B. Ultimate Tensile Strength

The load-displacement characteristics shown below (Figure 9) convey the variation in UTS among the alloy and its composites. It was noted that the UTS for base alloy to be 120.3MPa, Similarly the UTS for composite-1 was found to be 144.7MPa which shows an increase of 20.3% and UTS for composite-2 was found to be 138.4MPa which shows an increase of 15.05% when compared with the unreinforced eutectic Al–Si alloy (LM6). This is due to the fact that the lighter microspheres of fly ash act as barriers to the movement of dislocation, thereby increasing the ultimate tensile strength of the composite [7].

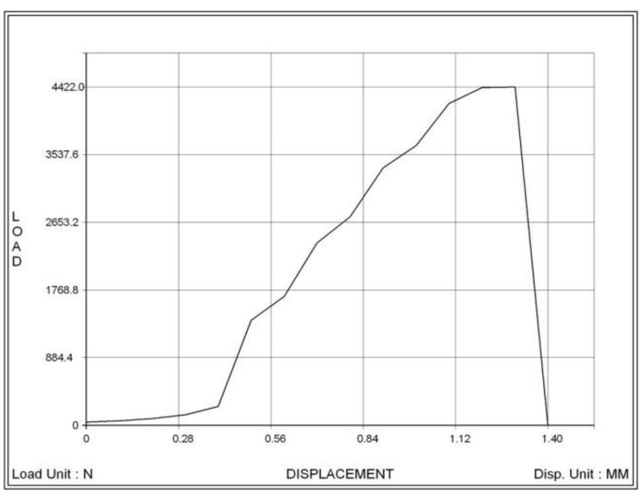
Further, dispersion of hard ceramic particles in a soft ductile matrix results in improvement in strength. This may be attributed to large residual stress developed during solidification and to the generation of density of dislocations due to mismatch of thermal expansion between hard ceramic particles and soft Al matrix [8]. The reason for the improved strength can also be due to the different extents of good bonding between the fly ash particles with the matrix [9].



Base Alloy (LM6)



Composite-1

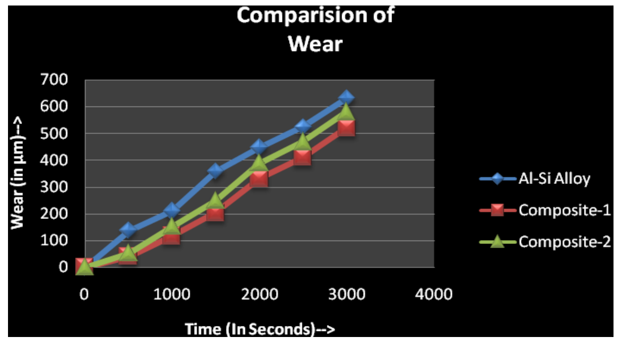


Composite-2

Figure 9 Load Displacement curves

C. Wear

During the span of 3000 seconds, Al-Si alloy exhibited a wear of 630μm, where as composite-1 and composite-2 indicated a wear of 520μm and 580μm respectively, which proves that composites resist wear better than the base alloy and composite-1 resists the best. This is due to the fact that fly ash contains hard abrasive particles and hence resists wear better than the matrix. Similar trends were observed by other researchers [10-14]. The comparison of wear behavior is as shown in the curves below:



6. CONCLUSION

In this investigation, an attempt has been made to compare some prime mechanical and tribological properties of the composites of LM6 such as hardness, tensile strength, wear resistance, formed out of different fly ashes and the results of this investigation reveal the following:

1. The hardness increased by 18.5 % over that of the base alloy in case of composite-1 and an increase of 13.8% in case of composite 2 .

2. The tensile strength increased by 20.3% over that of the base alloy in case of composite-1 and an increase of 15.05% in case of composite 2 .

3. The wear resistance increased by about 55 % over that of the base alloy in case of composite-1 and an increase of 45% in case of composite 2 .

It is clear that composite-1 which is made out of fly ash A proved more enhancement than composite-2 which is made out of fly ash B in every aspect. Fly ash A is rich with carbon (5.6wt%) which may be one of the reason of enhancements, but this is well explained by the percentage of fly ash dispersed and the composition of the fly ash i.e. composite-1 is formed with a

fly ash whose micrographs indicate an irregular particle geometry which makes it more dispersive i.e. more amount of fly ash get dispersed in to the matrix. As reported by many researchers [15, 16] that with increase in percentage of fly ash, the extent of enhancement also gets better, which happens to be the reason of more enhancement observed in case of composite-1.

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